June 1954

Bulletin 532

THE BEAN WEEVIL AND ITS CONTROL

F. H. LATHROP

Maine Agricultural Experiment Station
University of Maine
Orono, Maine

ACKNOWLEDGMENTS

Grateful appreciation is expressed to all who cooperated in the development of this bulletin.

Special credit is due to Burnham and Morrill Company and to Monmouth Canning Company, both of Portland, Maine, for their cooperation in large-scale tests of diatomaceous dusts for weevil control.

The active and interested cooperation of Mr. Norman Elliott, Manager of the Monmouth Canning Company plant at Freedom, Maine, was of great value.

The painstaking work of Mr. Frank Berry, student assistant, was helpful in preparing the data.

SUMMARY

The bean weevil is a destructive pest of dry beans. Loss from weevil injury occurs on the farm, in the home, and in commercial storage. Although some kinds of beans appear to be more easily damaged than others, all of the common varieties may be severely damaged by weevils.

Weevil attacks upon the drying beans may begin in the field. Infestation continues when the beans are placed in storage, and may spread to beans throughout the storehouse.

In its development, each weevil passes through four life stages: (1) The *egg* is laid among the beans by the female weevil. (2) The grub-like *larva* hatches from the egg, and promptly bores into a bean, where it feeds until grown. (3) The *pupa*, or resting stage, develops from the full grown larva within the bean. (4) The *adult weevil*, either male or female, transforms from the pupa, and immediately bores out of the bean. Mating occurs, and the female lays the eggs for the next generation.

In storage, the adult weevils do not feed; in the field, they probably drink droplets of moisture from the surface of the bean leaves.

The physiological activity of the weevil larvae causes severely infested beans to heat. The heating of the infested beans may enable the infestation to continue to build up during periods when the temperature of noninfested beans is too low for weevil development. However, during periods of warm weather the temperature of infested beans may become too high for the most rapid development of the weevils.

Control Methods

For the control of the bean weevil, the primary effort should be directed toward prevention, for even light infestation may ruin the beans for any practical purpose. Thorough clean-up is essential. Regardless of what other control methods may be used, it is of primary importance to clean up infestation, and keep the premises free from infested beans. Even a pint of infested beans may produce weevils to spread infestation throughout the storehouse.

Fumigation, properly conducted, under favorable conditions, will kill all stages of the bean weevil. The results of fumigation may be disappointing, however. The fumigated beans are likely to become reinfested.

Cold and heat are effective as controls also. Weevils can not develop in beans stored at a temperature of 50° F. or lower. Storage of the beans in a cold place sometimes is the easiest method of protecting home-stored beans from weevils.

Heating at about 131° F. for about 30 minutes will kill all stages of the bean weevil. Time should be allowed for the entire mass of beans to reach the killing temperature. Care is necessary to avoid destroying the germination potential or injuring the cooking qualities of the beans.

Mixing ½ teaspoon of ordinary, good quality, black pepper, per pint of beans, gives high degree of protection from weevils. The pepper can be removed without difficulty, before the beans are cooked. The black pepper treatment seems practical for small quantities of home-stored beans. The cost, however, probably would be too great for commercial use.

A commercial grain dust (Pyrenone) containing, as active ingredients, 0.80 per cent piperonyl butoxide and 0.04 per cent pyrethrins combined with an inorganic dust base, gave protection against bean weevils, apparently about equal to the best diatomaceous dusts. With an organic base (wheat dust), the Pyrenone was somewhat less effective. The active ingredients in Pyrenone Grain Dusts are said to be so little toxic to humans, that the dust probably is not objectionable when mixed with stored beans.

Diatomaceous dusts are probably the outstanding possibility for commercial usage. Two brands of diatomaceous dust, Celite 209, and Dicalite I G 3, were found to be effective. From ½ to 2 ounces of the dust per 100 pounds of beans, was found to give effective protection against weevil infestation likely to occur in commercial storage.

One commercial plant developed machinery for efficiently mixing the dust with the beans, and treated 100 tons of beans with one ounce of dust per 100 pounds of beans. No infestation was observed in the treated beans.

Bean weevil larvae penetrated untreated grain-bag cloth, and infested beans within the bags. Beans in similar bags, having the cloth impregnated with Celite 209, remained free from weevils.

The diatomaceous dust contains no toxic, insecticidal agent, and it is readily removed by washing. At the dosages suggested, the dust does not appear to be objectionable when mixed with the stored beans. The dust is effective as long as it remains on the beans, and the dust-treated beans are not subject to reinfestation. The dust treatment is inexpensive, and appears promising for general use.

BULLETIN 532

THE BEAN WEEVIL AND ITS CONTROL

F. H. Lathrop[1]

BEAN WEEVIL IS DESTRUCTIVE INSECT

The bean weevil, *Acanthoscelides obtectus* (Say), is a destructive pest of dry beans in Maine. Infestation may begin on the farm and continue into processing plants. Loss from weevil infestation is a constant threat to the dry bean grower. Perhaps the most frequent loss occurs in home-stored beans. There, though individual loss is seldom great, considering the large number of homes in which damage occurs, the total destruction is important. Probably the greatest individual losses occur in processing plants, where large quantities of beans are stored. Here control of the bean weevil is imperative, with the threat of a destructive outbreak an ever-present possibility.

Because of the importance of the problem, the Maine Station, for a number of years, has conducted an investigation of the bean weevil to develop practical methods of dealing with the pest under Maine conditions.

Nature and Extent of Injury

The bean weevil attacks practically all varieties of common beans. Larson and Fisher (1938)[2] in their comprehensive study of the pest, reared the bean weevil from more than 50 varieties of beans, and state that they did not find a single variety in which the weevils did not breed freely.

Usually the first indication of weevil infestation is the appearance of the exit holes in the beans. (Fig. 1) Severely infested beans soon become riddled with holes and completely tunnelled by the weevils. Such beans, of course, are of no possible value. Even a light infestation may render the beans unsalable and unfit for food.

As the weevil infestation progresses, the injured beans lose weight (Table 1).[3] By the time the infestation has run its course, weight loss may be as much as 40 or 50 per cent. This loss is of secondary importance, however, for the infested beans are of little or no value long before there is material loss of weight.

---

[1] Head, Department of Entomology, Maine Agr. Exp. Sta.

[2] Literature cited is listed in full on page 35.

[3] Tables begin on page 20.

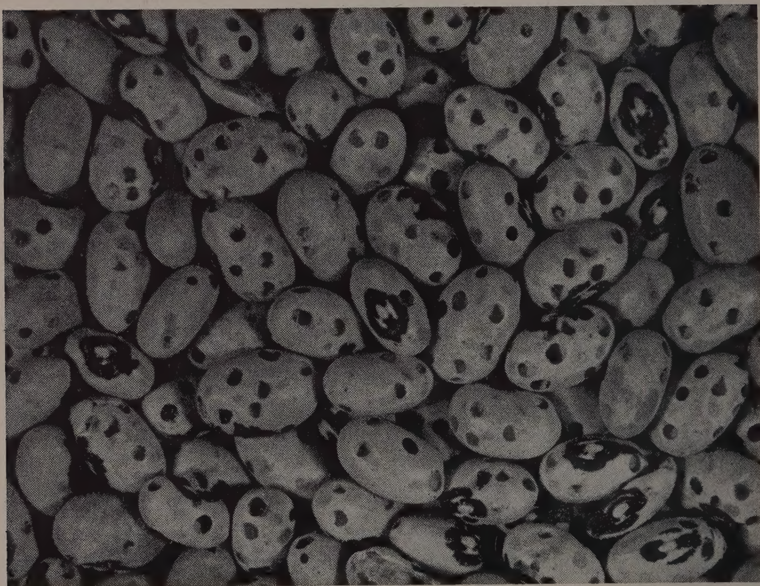

FIG. 1. Severely injured beans, showing the holes from which adult weevils emerged.

Infestation May Begin in the Field

The weevils may attack the beans in the field, where eggs may be deposited within the drying and cracking bean pods. Larvae hatch from the eggs, and tunnel into the beans within the pods. When the infested beans are harvested and placed in storage, severe infestation is likely.

Through the cooperation of the County Agents and a number of bean growers in the fall of 1949, a 1-quart sample of beans was collected from each of 17 farms in various localities in Maine. An effort was made to obtain each sample before the beans were exposed to infestation in storage. The samples were sent to Orono, where they were stored in insect-tight containers, placed in a warm room. Subsequent inspection showed that two of the samples developed weevil infestation. This test suggests the strong probability that weevil infestation may originate in Maine bean fields.

Infestation in Storage

In storage, the weevils continue to thrive and multiply as long as the temperature is 60° or 70° F. or higher. Infestation in the storage may be started by infested beans brought in from the field, or from some

other storage house. Once infestation starts, the weevils may spread through the storehouse. Adult weevils may lay their eggs on the bags of beans, and the little larvae can readily crawl through the meshes of even tightly-woven grain bags. No unprotected beans are safe from weevils, if there are any infested beans in the storehouse.

BIOLOGY OF THE BEAN WEEVIL

The Life Stages

In the course of its development, each bean weevil passes through four life stages: (1) The *egg* is laid loosely among the beans by the female weevil. (2) The grub-like *larva* (Fig. 2) hatches from the egg. The newly hatched larva promptly bores into a bean, where it tunnels and feeds until full grown. (3) The *pupa* (Fig. 2), or resting stage, develops from the full grown larva within the bean. (4) The *adult weevil* (Fig. 2), either male or female, transforms from the pupa, and immediately bores out of the bean. The male and female weevils mate, and the female lays the eggs for the next generation.

FIG. 2. Life stages of the bean weevil. From left to right: Full grown larva. Adult weevil or beetle. Pupa or resting stage. The short line to the right of the weevil shows the actual length of the insect. From U.S.D.A. Farmers' Bulletin 1275.

Adult Weevils and Their Activities

The adult is a small, hard-shelled beetle, about ⅛ inch long, and nearly as wide. It is of a dull, grayish-brown color. Under a magnifying lens, a rather obscure pattern of slightly lighter and darker markings can be seen on the wing covers, and the legs and antennae are found to be somewhat reddish in color.

The adult weevils living among stored beans do not feed. If water or sugar syrup is supplied, however, the weevils will drink the liquid. It

has been found (Larson and Fisher) that weevils fed with water, honey, or sugar syrup, laid more eggs, and continued laying over a longer period than weevils not supplied with nourishment. It seems probable that bean weevils living outdoors drink dew and other moisture from the surface of the bean plants.

The adult bean weevils crawl and fly actively at room temperature (70° to 75° F). As the temperature increases, the weevils become more active, and as the temperature decreases, they become less active. At a slight disturbance, a sharp jar or upon being touched, the weevils have a habit of "playing dead," by folding the legs tightly against the body, and remaining completely motionless. This often makes it difficult to determine whether a weevil is alive or dead.

The adult weevils usually are positively phototactic, that is they have a habit of crawling and flying toward a source of light. Weevils escaping in a room usually fly toward a window, and accumulate on the window glass. The adults usually are also negatively geotactic, for they have a habit of moving upward against the force of gravity. Both of these reactions appear strongest when the weevils are attempting to escape from severely infested beans where the weevil population is overcrowded. When weevils are placed in a container of fresh, weevil-free beans, the insects most frequently crawl promptly down among the beans.

Oviposition and the Egg

The bean weevil egg is very small, approximately 1/40 inch long. It is slender, with rather broadly rounded ends, and whitish in color.

In storage, most of the eggs are laid loosely among the beans, but usually a few are attached lightly to the beans or to the walls of the container. The bean weevil does not attach its eggs firmly either to the beans or to other objects.

Egg laying usually begins within two or three days after the weevil emerges, and continues through most of the life of the female. Manter (1917) in Connecticut observed that the egg laying period of 37 individual females varied from 3 to 18 days, with an average of 8 days.

In his studies at Ithaca, New York, Menusan (1934) recorded an average of 67 eggs per female, based on 27 individuals at 27.1° C. (80.8° F.). At that temperature, 95 per cent of the eggs were deposited during the first 6 days, and oviposition continued as long as 12 days. He also reported (1935) oviposition periods from 1 to 68 days, depending upon temperature, and the largest numbers of eggs per female were deposited at temperatures between 21.0° C. (69.8° F.) and 27.1° C (80.8° F.).

In Maine, 50 weevils (males and females not distinguished), in groups of 10, were placed with stored beans, in darkness, at warm, room temperature (70°-80° F.). A total of 1139 eggs were collected through the oviposition period. The results are summarized in Table 2. The length of the oviposition period of the individual females was not determined, but for the group as a whole, egg laying continued through 21 days. It was observed that 50 per cent of the eggs were laid in 6 days, 75 per cent in 8 days, 90 per cent in 12 days, and 95 per cent in 14 days.

The development of the embryo weevil larva within the egg proceeds rapidly at room temperatures, and in three or four days the head and the body segments of the developing larva can be seen distinctly by microscope through the egg shell. When ready to emerge, the little larva gnaws a ragged hole and crawls out. Usually the larva emerges from the larger end of the egg, but sometimes it gnaws its way out farther down the side of the egg.

The Larva and Larval Activities

The newly hatched bean weevil larva is somewhat grub-like in appearance (Fig. 2). It is whitish in color with a slightly darker head, and is very small—about 1/50 inch long. The little larva crawls actively until it reaches a place favorable for boring into a bean. The larva usually bores in at the point of contact between two beans, or where a bean contacts the wall of the container or some other solid object. The larva also may enter where the seed coat of the bean is broken. In boring into a bean, the larva gnaws a small round hole through the surface. The entrance hole is so small that it is barely visible. The entrance is marked by a small pile of chewed material, frass, cast out by the larva, and for a time remains around the hole. The frass is loose in texture, and usually is brushed away as soon as the beans are disturbed. Larson and Fisher observed that two or more larvae, in succession, may go in through the same entrance hole.

Within the bean, the larva feeds and grows. When full grown, the larva tunnels out an oblong, rounded cavity or cell just beneath the skin of the bean. Apparently the cell is lined with a cement-like exudate. Within the cell the larva stops feeding, becomes inactive, and changes to the pupal or resting stage. The full grown larva is fat and grub-like in appearance, whitish in color, with a dark head. Although it usually assumes a curved or "rolled up" posture, the mature larva is nearly ⅕ inch long.

Detailed studies of larval development (Larson and Fisher) show that the active, growing larva, within the bean, sheds its skin (molts) three times, and then again for the fourth and last time, in the pupal cell, immediately before pupation.

The larva, of course, is the destructive stage of the bean weevil. In a quiet room, the chewing of the numerous larvae, within even a small quantity of severely infested beans, can be heard distinctly. The sound has much the quality of gentle breeze blowing over dry leaves on the ground in the fall.

The Pupa or Resting Stage

The newly formed pupa of the bean weevil (Fig. 2) is whitish in color, with a smooth, somewhat glistening surface. As the pupa transforms from the larva, it becomes shorter, until it is about ⅔ to ¾ the length of the larva from which it developed. Examination under a magnifying lens reveals the developing adult structures, folded and delicately outlined on the surface of the pupa. The color of the pupa gradually darkens as the time for the emergence of the adult approaches.

When the adult bean weevil finally develops from the pupa, it cuts out a perfectly round hole through the skin, or seed coat, of the bean, and emerges. The little round section of the seed coat may remain loosely attached like a cover over the weevil exit hole. But most of the disks become detached from the beans, and many accumulate at the bottom of the container. The adult males and females soon mate, and within a few days begin laying eggs to produce the next generation.

Duration of the Developmental Stages

The length of the stages in the development of the bean weevil is influenced by several factors. Temperature and humidity are especially important. The food, that is the kind and the moisture content of the beans, also has been found to have an effect upon weevil development.

The incubation period of the bean weevil eggs has been reported to be as short as 3 days (Larson and Fisher), and as long as 44 days (Menusan 1934). That the time required for the eggs to hatch varies with the temperature, has been observed by many investigators. Menusan found the incubation period to be shortest (4.4 days) at 30.1° C. (86.2° F.) and was longer when the temperature was either higher or lower.

As observed in Maine, the incubation period varied from 6 to 13 days, see Table 3. The time required for 50 per cent of the eggs to hatch varied from 6.2 days at 89.6° F. to 10.3 days at 72.5°. These data appear to agree reasonably well with the results of Menusan's (1934) careful experiments.

Larson and Fisher observed that the larval stage of the bean weevil may be as short as 12 days, or may continue for 6 months or longer, de-

pending upon the surrounding temperature and humidity, and also upon the kind of seeds in which the larvae are feeding.

The duration of the pupal stage has been reported to extend from 8 days to 25 days or longer (Manter, 1917, and Larson and Fisher). In the Maine study, no attempt was made to determine the duration of the larval stage and the pupal stage separately. The total developmental period—from the depositing of the egg, to the emergence of the adult weevil—was determined, however, Table 4. The total developmental period of the bean weevil, in studies conducted at Orono, Maine, was observed to range from a minimum of 28 days at 89.6° F. to a maximum of 61 days at 76.2° F.

Overwintering of the Weevil

The bean weevil spends the winter in and among infested stored beans. During cold weather, in unheated storage rooms, the activities of the weevils are reduced to a minimum. Prolonged or extreme cold will kill all stages of the weevils. In laboratory tests, all stages were killed by 24 hours exposure to 0° F. In many storage places, the temperature remains at least high enough to permit the weevils to survive the winter, and where the temperature is maintained at about 70° F., the weevils may continue to thrive and multiply throughout the winter.

There is no direct evidence available to show that the weevils can survive the winter outdoors in Maine. In the fall of 1941, four 1-quart lots of beans infested with all stages of the weevils, were placed outdoors on a bed of hay 12 inches deep, and covered with 24 inches of hay. Observations the following spring showed no survival of any stages of the weevils. Although it seems that weevils may possibly survive the winter outdoors, under very favorable conditions, the important survival in Maine occurs indoors among stored beans.

Infestation Causes Heating of Beans

That insects may cause infested grain to heat, has been observed and discussed by many authors.

To measure the heat produced by bean weevil infestations, six containers were prepared as follows: A 1-quart cylindrical, fiber container was nearly filled with 800 grams of Yelloweye beans. The container was then placed in a similar container of 1-gallon capacity. The space between the walls of the two containers was snugly packed with cotton batting to reduce the rapid loss of heat from the smaller container. A chemical thermometer was fitted snugly through a hole in the center of the covers of the two containers, so that the temperature at the middle of the mass of beans could be read from outside. The beans in each of

five of the containers were infested with 100 adult weevils. One container was left without weevils, for comparison.

The results are shown in Table 5, which shows the temperatures in two typical infested containers, compared with the temperatures in the noninfested container. The two infested containers in Table 5 were especially favorable for comparison, because they were infested on the same day, and they continued through the same period.

During the first 10-day period, the temperature of the infested beans averaged slightly lower than that of the noninfested beans. This initial decrease in temperature occurred in all but one of the containers of infested beans in which the temperatures were observed.

The first rise in temperature in the two containers (see Table 5) occurred between 21-30 days after infestation. The rise (average 5.8° F. above the noninfested beans) was not great, and was of short duration. A second, and greater rise in temperature occurred during the period 51-80 days after the weevils were placed in the containers. A third, and a fourth rise occurred during the periods 101-120 and 131-160 days after infestation. The data in Table 5 show that the periods of low temperatures, between the rises, were shorter, and the temperatures during the low periods remained higher, as the infestation progressed. Following the fourth, and last, high temperature period, the temperature of the infested beans gradually subsided, until the temperatures of the infested and the noninfested beans became equal. At this point, it was found that the beans in the infested containers were so completely riddled that they apparently could no longer support developing weevils, and the infestation had died out.

The periods of high temperature in the infested beans coincided with periods of intensive larval activity. The chewing sounds in the beans became loudest at the peak of the high temperatures, and subsided as the temperature declined. It seems probable that the increased temperature of the infested beans resulted largely from the metabolic activity of the bean weevil larvae. Flanders (1932) suggested that the heat produced by grain-infesting insects may be due, in part, to the friction of the mandibles of the larvae during feeding. He reported (1930) that the "heat of infestation" from the grain moth, *Sitotroga cerealella,* was sufficient not only to continue the infestation without the application of artificial heat, but that it was necessary to cool the grain to hold the temperature down to the optimum, 85° F., for the development of the insects.

As pointed out by Back (1939) the spontaneous heating of infested beans is of considerable importance. Even during the winter months, when the temperature of noninfested beans is too low for weevil develop-

ment, infested beans may maintain a temperature high enough to stimulate the continued build-up of weevil infestation. The higher temperature of infested beans can be detected in the warehouse by passing the hand over the sacks of beans. Thus the experienced warehouseman can locate centers of weevil infestation in tiers of sacked beans. The peculiar, disagreeable odor given off by the warm, infested beans also serves as an aid in locating them.

Probably, during the summer months, the heat of infestation rather frequently raises the temperature of infested beans high enough to retard the development of the weevils. The highest temperature recorded in the infested beans was 103° F., when the temperature of the non-infested beans was 78° F. Menusan (1934) stated that the "optimum temperature for egg, larval and pupal development is approximately 30° C. (86° F.). Either an increase or decrease in temperature from the optimum increases the mortality and the length of time required for development. Optimum temperature for the adult as measured by amount and rate of oviposition was 27° C. (80.6° F.)." The data in Table 5 show that there were several periods when the average temperature of the infested beans was considerably higher than 86° F., and therefore, probably had more or less retarding effect upon the build-up of weevil infestation during the periods of high temperature.

CONTROL OF THE BEAN WEEVIL

Clean-up of Infestation

Even as little as a pint of infested beans can produce more than enough weevils (Fig. 3) to spread the pest throughout even a large storage warehouse, or to start infestation in a field of beans. As the first step toward control, every effort should be made to rid the premises completely of infested beans, whether the infestation occurs in the home, in the farm storehouse, or in the large commercial warehouse. No infested beans should be overlooked—however small the quantity may be. The floors and walls of storage bins, and other places where beans are handled, should be swept clean. All beans should be cleaned from cracks and corners and other out-of-the-way places. All of the machinery used in handling, cleaning, and grading the beans should be examined thoroughly, and all beans, whether infested or not, should be removed from the machinery.

Small quantities of infested beans, and the sweepings from the clean-up routine, should be burned immediately. Larger quantities of beans, if not too severely infested, may be fumigated or otherwise treated to destroy the insects, and then the beans may be picked over and salvaged if it seems desirable.

FIG. 3. One pint of severely injured beans, and 10,400 weevils that came from them. A small quantity of infested beans can produce enough weevils to infest a large storage.

Fumigation

Fumigation is used frequently for cleaning up infested beans. If properly conducted, under favorable conditions, fumigation will kill all stages of the weevils. If not properly conducted, or if conditions are not favorable, fumigation is likely to be disappointing. After the beans have been fumigated, they are subject to reinfestation, and precautions should be taken to protect the fumigated beans from renewed attacks by the weevils.

Methods for effective fumigation have been worked out and published by other agencies (see U. S. Dept. Agr. EC-27 "Control of Insects That Attack Dried Beans and Peas in Storage," Nelson and Fisher, 1952). Therefore, no detailed discussion of fumigation is included in this bulletin.

Effect of Cold and Heat

In laboratory tests, it was found that beans stored at a temperature of 50° F., or lower, did not become infested, in spite of the fact that the beans were exposed to infestation. Menusan (1934) showed that bean weevils do not produce eggs when the temperature is 50° F. or lower. Back stated that no development of the weevils takes place at 50° F. or lower, and that no stage of the bean weevil can withstand exposure of 56

days at 31° to 32° F. He found, however, that infestation may survive 66 days at 36° F.

Especially for the home storage of small quantities of beans, it often is practical to keep the bean supply where the temperature remains cold enough to prevent the development of weevil infestation. In attempting to use cold storage for weevil control, however, it is important to be sure that the temperature of the beans remains low, and does not rise much above 50° F. long enough to stimulate weevil development.

High temperature is effective for killing bean weevils. The data shown in Table 6 are from Back. It is evident that a temperature of about 130° F. will kill all stages of the bean weevil in a short time. However, considerable time is required to heat the mass of beans to the killing temperature. Unless great care is used, the beans may be overheated, and the germination injured, which is important if the beans are to be planted. If the beans are scorched, their value for cooking may be reduced.

In the home, small quantities of beans can be heated in the kitchen oven, to kill the weevils.

On a commercial scale, machines are available for rapidly heating and drying the beans. When properly used, the drying machines are said to destroy all stages of the weevils, and by reducing the moisture content, increase the resistance of the beans to weevil injury.

EXPERIMENTS ON WEEVIL CONTROL

The generally recommended treatments for weevil control—fumigation, low temperature, and high temperature—are all difficult to use, expensive, liable to failure, and leave the beans subject to reinfestation by weevils. Because of the need for a simple, more dependable, and less expensive method, the Maine Station undertook an investigation of bean weevil control.

Dust Treatments

Black Pepper. Previous publications (Freeborn and Wymore 1929, Harvill, Hartzell and Arthur 1943, McIndoo and Sievers 1924, Synerhold 1945) had reported on the insecticidal properties of black pepper and related chemical compounds. Although the previous tests were against other insects, it was not surprising that black pepper was found to be effective for protecting beans against weevil attack (Lathrop and Keirstead, 1946). The tests by Lathrop and Keirstead during World War II showed that one teaspoon of pepper was required for reliable protection of the beans. After the war, fresher or better quality pepper became available, and the tests recorded in Tables 8, 9, 10, and 11 show

that as little as ½ teaspoon of black pepper per pint, thoroughly mixed with the beans, gave a high degree of protection from weevil infestation.

Apparently the particle size of the pepper is a factor influencing the effectiveness. The data in Tables 10 and 11 suggest that finely ground black pepper is somewhat more effective than the ordinary grind. The mixture of dry, ground mustard, or of wheat flour, with equal parts of black pepper, reduced the effectiveness of the pepper (Table 8).

That the protective properties of black pepper may persist for as long as a year after the beans are treated, is shown in Tables 10 and 11.

Black pepper has the advantages of being readily available in the home, of being practically nontoxic to humans, and it can be removed easily by washing the beans. But probably the cost of the black pepper would discourage its use for large quantities of beans.

Pyrenone Grain Dust. Two samples of a commercial dust known as Pyrenone Grain Dust were tested against bean weevil. Both samples contained 0.80 per cent piperonyl butoxide and 0.04 pyrethrins as the active insecticidal agents. In one sample the active agents were combined with an organic base (wheat dust). In the other sample the active agents were combined with an inorganic base. The test (Table 11) showed that the Pyrenone Grain Dust with the organic base was about as effective as black pepper for protecting the beans from weevil infestation. The Pyrenone Grain Dust with the inorganic base was more effective, and appeared to be about as effective as the diatomaceous dust, Celite 209.

The active agents in Pyrenone Grain Dust are said to be only very slightly toxic to humans, and the dust can be washed from the beans without difficulty. The cost probably is low enough to permit the use of Pyrenone Grain Dust on large quantities of beans for weevil control.

Diatomaceous Dusts. It has been known for many years that inert dusts, such as lime and talc, when mixed with stored, dry beans or grain, gave considerable protection against insect pests (Metcalf 1917, Back 1939). The employment of inert dust has never come into general use, however, because the large quantity of dust recommended is objectionable when mixed with the beans. Usually one pound of dust was added to every six or eight pounds of beans. At such concentrations, the dust appeared to serve as little more than a mechanical barrier to the weevils. Nevertheless, the investigation of the dust treatment appeared to offer a possibility for developing an improved method for weevil control.

The details of the tests of inert dusts, and the results, are shown in Tables 7 and 11 to 21, inclusive.

Of all the inert materials tested, only the uncalcined diatomaceous dusts appeared to show superiority. Celite 209 and Dicalite IG 3 are two kinds of diatomaceous dust that gave sufficient protection, even when the

beans were exposed to severe weevil infestation, to warrant recommendations for their use.

During recent years, much research has been devoted to the effects of inert dusts upon stored grain insect pests. The effect of the dust usually has been ascribed to the scarification of the integument of the insects, especially the adults, and the rapid loss of moisture from the insects, as a result of the injury to the integument (Briscoe 1943).

In the tests reported here, the dusts appeared to have only a minor effect upon the adult weevils. The important effect was upon the newly hatched larvae. When viewed under the microscope, it was repeatedly observed that when a newly hatched weevil larva came into contact with Celite 209 or Dicalite IG 3, dust particles adhered to the tips of the larval hairs, and apparently the dust stimulated the flow of mucous from the surface of the larva. The affected larva writhed violently, and became balled with a coating of the dust particles. The dust-coated larva lost its power of locomotion, and usually died before it could bore into a bean. Unfortunately, the characteristics required to render the dust effective, have not been determined. Probably the effect of the dust is determined by the physical characteristics of the dust particles.

The data presented in Tables 7, 11, and 13 to 20, inclusive, show that diatomaceous dust in quantities as small as 1/16 teaspoon per pint of beans delays the development of weevil infestation. When Celite 209 or Dicalite IG 3 was used, ½ teaspoon per pint of beans was sufficient to protect against any weevil infestation that probably would be encountered in a commercial storage. Data presented in Table 16 show that when five weevils were added to each of four lots of 400 grams of untreated beans, severe infestation developed in two of the containers; infestation failed to develop in the other two. Practically no infestation developed in similar lots of beans treated with 1/16 or ⅛ teaspoon of Celite 209, even when as many as 80 weevils per lot were introduced into the containers. It seems probable, therefore, that a small quantity of Celite 209 or of Dicalite IG 3 will protect beans against ordinary infestations of weevils.

Through the cooperation of two commercial processing plants, tests were made by treating 25-pound lots of beans. Dosages of ½ ounce, ¾ ounce, 1 ounce, and 2 ounces of dust per 100 pounds of beans were tested.

In the test shown in Table 19, the beans were already infested with weevil larvae before the test was started, and a pill box of 20 infested beans was placed in the bag with each 25-pound lot of beans. The beans in the untreated bags developed very severe infestation. The infestation in the treated bags apparently did not progress much beyond the infesta-

tion originally present before the treatment was applied. This probably should be regarded as an extremely severe test of the dust treatment.

In the test shown in Table 20, the beans were free from infestation prior to the test. Severe infestation did not develop in any of the treated beans, even though each of the 25-pound lots was subjected to extremely severe invasion by weevils.

Following the cooperative tests with 25-pound lots of beans, one commercial bean-processing plant constructed equipment for rapidly and efficiently mixing beans with diatomaceous dust. In the early spring of 1953, the plant treated 100 tons of beans with Dicalite at the rate of 1 ounce per 100 pounds. The beans were processed and canned through the summer. Infestation was not observed in any of the treated beans. This demonstration by the commercial bean-processing company is interesting, but, of course, cannot be regarded as an absolute test, be-

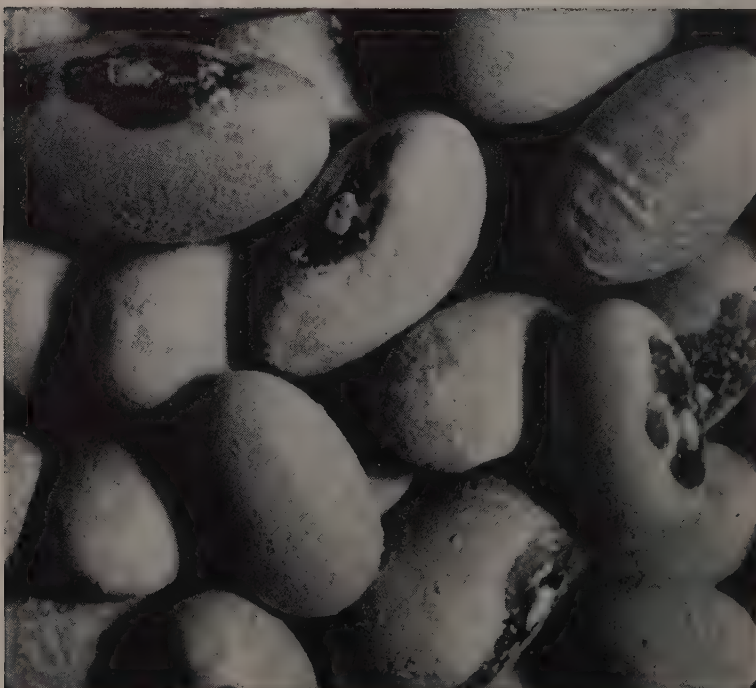

FIG. 4. These beans were protected from weevils by the application of one ounce of diatomaceous dust per 100 pounds of beans. The beans are enlarged about three times natural size, to show the dust on the surface. Diatomaceous dust is not poisonous to humans, and it readily washes off when the beans are prepared for cooking.

cause it is not known that the treated beans were subjected to attack by weevils.

Observations of the bean weevils showed that the adult weevils cannot penetrate tightly woven grain-bag cloth. The weevils may lay their eggs upon the outside of the bags, however, and the newly hatched larvae can pass through the meshes of the cloth without difficulty. Larvae can also pass from one bag to another, and thus may spread weevil infestation. Table 18 shows that weevil larvae penetrated untreated grain-bag cloth having 40 x 40 threads per inch. When similar grain-bag cloth impregnated with Celite 209 dust was tested, however, the larvae did not infest the beans within the bags.

The tests appear to show that ½ to 1 or 2 ounces of Celite 209 or Dicalite IG 3, per 100 pounds of beans, can effectively protect the beans from attacks of bean weevils. Celite 209 and Dicalite IG 3 have certain advantages for use against bean weevils. These materials contain no toxic ingredients. They are removed from the beans without difficulty in the routine processing procedures. The protection of the beans appears to be effective as long as the dust remains on the beans. The cost of treatment is very slight.

EXPERIMENTAL METHODS—DATA

Yellow Eye beans, excepting in a few instances which are noted, were used for the biological studies and for all of the tests of weevil control.

For all tests, unless otherwise stated, the following conditions applied: The beans were placed in 1-quart, cylindrical, fiber containers, with 400 grams of beans (approximately 1 pint) in each container. Four containers were employed for each test item shown in the tables. The containers of beans were kept on shelves in the laboratory at room temperatures usually ranging from 70° to 80° F.

To save time and effort, the dusts used in the tests were measured by volume (teaspoon) rather than by weight. Table 21 gives a list of the dusts tested, and the weight of one teaspoon of each. If desired, the volumes of dust used in the tests can be converted to weights.

Infestation was introduced into the containers by mixing infested Red Kidney beans with the test beans before the treatment was applied and, after the treatment was applied, by placing a pill box of infested beans on top of the test beans, or by placing adult weevils in the container after the treatment was applied. The pill boxes were punctured with holes to permit the escape of weevils from the pill boxes into the test container. In general, the infestation introduced in the tests was much greater than probably would be encountered in commercial bean

storages. Most of the treatments, therefore, were subjected to extreme tests.

Results were determined by observations of the beans, and by weighing from time to time. In some of the tests, counts of the percentage of beans having weevil exit holes were made at the conclusion of the test. Generally the tests were continued until infestation had run its course, and practically all of the weevils had died.

The following tables present the data referred to in this bulletin.

TABLE 1

Loss of Weight of Beans Injured by Bean Weevils

	Dates beans were weighed				
	1952	1953			
	Dec. 3[1]	Feb. 5	Mar. 16	Apr. 28	Aug. 4
Weight (grams)[2] noninfested beans[3]	400	396	393	395	404
Weight[2] infested beans	400	391	362	312	220
Loss of weight[2] infested beans	—	5	31	83	184
Percentage loss infested beans	—	1.3	7.9	21.0	45.5

[1] Dec. 3, 1952—Infestation started. Original weight of beans, 400 grams in each container.
[2] Average weight of beans in 4 containers noninfested beans, and 4 containers infested beans.
[3] The weights of the noninfested beans varied from time to time, because the beans lost moisture during the winter, when the air was dry, and absorbed moisture during the spring and summer, when the air was moist.

TABLE 2

Summary of Data on Egg Laying by 50 Weevils (Males and Females Not Distinguished) Through the Combined Oviposition Period

Orono, Maine. February 25 to March 17, 1943

Percentage of eggs laid	4	10	25	50	75	90	95	100
Days of oviposition	1	2	3	6	8	12	14	21

TABLE 3

Incubation Period of Bean Weevil Eggs in Relation to Temperature
Orono, Maine. February 24-March 17, 1953

Mean temperature (° F.)	Number of eggs hatched	Incubation period		
		Minimum days	Maximum days	Mean[1] days
72.5[2]	105	9	13	10.3
75.8[2]	232	8	13	9.5
80.6[3]	123	7	9	7.2
89.6[3]	116	6	10	6.2

[1] Mean incubation period extends from deposition of the eggs to 50 per cent hatch.
[2] Average of daily means of maximum and minimum temperatures observed in storeroom.
[3] Constant temperature in temperature-controlled cabinets.

TABLE 4

Developmental Period[1] of the Bean Weevil in
Relation to Temperature
Orono, Maine. February 27-April 29, 1953

Mean temperature (° F.)	Number of weevils observed	Developmental period		
		Minimum days	Maximum days	Mean[2] days
76.2[3]	81	47	61	52.9
80.6[4]	155	35	52	37.3
89.6[4]	104	28	46	32.5

[1] Developmental period extends from the depositing of the eggs to the emergence of the adults.
[2] Mean developmental period extends from the depositing of the eggs to the emergence of 50 per cent of the adults.
[3] Average of daily means of maximum and minimum temperatures observed in storeroom.
[4] Constant temperature in temperature-controlled cabinet.

TABLE 5

Heating of Beans, as a Result of Weevil Infestation
April 19-November 14, 1953

Period, days since infestation started	Average increase or decrease (-) in temperature[1] of infested beans			Average temperature[1] of non-infested beans	Average[2] room temperature
	Lot A infested	Lot B infested	Average A and B	Lot C	
	°F.	°F.	°F.	°F.	°F.
1-10	-0.9	-0.6	-0.8	78.0	77.5
11-20	3.0	-0.3	1.4	76.9	76.5
21-30	7.1	4.5	5.8	77.8	77.5
31-40	1.1	0.6	0.9	77.0	76.9
41-50	1.0	0.6	0.8	78.0	78.1
51-60	8.0	6.3	7.2	77.9	77.7
61-70	19.0	19.2	19.1	79.3	78.5
71-80	14.5	15.6	15.1	79.2	78.6
81-90	6.9	7.2	7.1	80.4	79.7
91-100	4.9	5.2	5.1	80.8	79.6
101-110	18.8	19.1	18.9	75.8	75.8
111-120	14.6	16.2	15.4	76.2	74.7
121-130	7.4	8.0	7.7	75.6	75.6
131-140	17.9	18.3	18.1	79.4	78.7
141-150	16.5	18.0	11.8	74.3	74.5
151-160	11.2	13.4	12.3	77.1	76.1
161-170	4.2	5.9	5.1	77.7	77.4
171-180	1.4	7.2	4.3	75.6	75.7
181-190	2.0	9.7	5.9	75.8	75.3
191-200	0.6	3.4	2.0	75.9	75.6
201-210	0	1.0	0.5	74.2	74.4

[1] Average of daily readings.
[2] Average of the means derived from daily maximum and minimum temperatures.

TABLE 6

High Temperature for Killing the Life Stages of the Bean Weevil
(Data from Back)

Life stages of weevil	Time required	Killing temperature
Embryos in eggs	10 minutes	125.6°F.
Newly hatched larvae	7	131°
Full grown larvae in beans	20	131°
Pupae	25	131°
Adult weevils	4	131°

TABLE 7

Comparison of Inert Dusts and Rotenone for Bean Weevil Control

Material	Beans per pound of dust	Percentage[1] of beans with holes	
		May 7, 1940	October 25, 1940
	(pounds)		
Diatomaceous dust (Celite 209)	12	.10	.25
Hydrated lime	12	.05	2.35
Bentonite	12	.30	.75
Talc	12	.85	4.60
Talc	24	1.25	26.40
Rotenone 0.75%	12	.25	2.95
Rotenone 0.75%	100	3.10	72.25
Rotenone 0.75%	200	1.60	69.70
Check			
No treatment		35.45	97.70

[1] Average of a random sample of 500 beans from each container.

Notes: Original weight of beans: 5 pounds in each container.
Container: Fiber, cylindrical, 1-gallon capacity.
Infestation introduced: December 14, 1939, 100 grams of heavily infested beans in ½-pint container placed on top of the 5 pounds of beans in the 1-gallon container.

TABLE 8

Comparison of Black Pepper, Dry Mustard, Wheat Flour, and Their Mixtures for Bean Weevil Control

Material	Quantity	April 15, 1949	Percentage[2] of beans with holes
		Loss of weight[1]	
	(teaspoon)	(grams)	
Black Pepper Mustard	⅛ ⅛	153.2	73.6
Black Pepper Wheat Flour	⅛ ⅛	206.5	97.2
Black Pepper Mustard	¼ ¼	95.7	50.7
Black Pepper Wheat Flour	¼ ¼	200.7	91.9
Black Pepper	½	4.0	2.6
Mustard	½	200.2	97.2
Wheat Flour	½	216.7	99.2
Black Pepper Mustard	½ ½	50.0	28.0
Black Pepper Wheat Flour	½ ½	180.0	92.0
No treatment, infested		221.5	99.9
No treatment, noninfested		—	0

[1] Average loss per container, compared to the weight of noninfested checks.
[2] Average of a random sample of 100 beans from each container.

Notes: Original weight of beans: 385 grams in each container.
Infestation introduced: April 22, 1948, before the treatment was applied, 11 infested Red Kidney beans were mixed with the beans in each infested container. After the treatment was applied, 10 adult weevils were placed in each container.

TABLE 9

Comparison of Several Brands of Black Pepper for Bean Weevil Control

Black pepper brand	Quantity	April 15, 1949 Loss of weight[1]	Percentage[2] of beans with holes
	(teaspoon)	(grams)	
Ann Page	1	8.8	.3
	1½	12.3	.7
	2	13.7	1.0
Dainty Dot	1	10.3	1.0
	1½	11.3	1.5
	2	14.3	.5
Durkee	1	10.3	.5
	1½	13.3	0
	2	13.0	0
Stickney & Poor	1	220.7	97.8
	1½	218.0	97.3
	2	144.3	81.3
Infested—no treatment		238.3	100.0
Noninfested—no treatment		—	0

[1] Average loss per container, compared to the weight of noninfested checks.
[2] Average of 2 random samples of 100 beans from each container.

Notes: Original weight of beans: 385 grams in each container.
Replication: 3 containers, each dosage, each brand, and the checks.
Infestation introduced: March 6, 1948. 18 infested Red Kidney beans mixed with the beans in each container, before the pepper was added. After the pepper was added, 10 adult weevils were placed in each container.

TABLE 10

Comparison of Black Pepper and Pyrenone Grain Dust for Bean Weevil Control

Material	Quantity	Dec. 4 1950	Mar. 14 1951	Sept. 28 1951	Feb. 12 1952	Oct. 4 1952
	(teaspoons)	Infestation				
Black Pepper Dainty Dot	¼	None	None	None	Moderate	Severe
	½	"	"	"	Light	Light
	1	"	"	"	None	None
	1½	"	"	"	"	"
Black Pepper McCormick, ordinary grind	¼	None	None	None	Moderate	Severe
	½	"	"	"	Light	Light
	1	"	"	"	None	None
	1½	"	"	"	"	"
Black Pepper McCormick, finely ground	¼	None	None	None	Light	Light
	½	"	"	"	None	None
	1	"	"	"	Light	Light
	1½	"	"	"	None	None
Pyrenone Grain Dust. Organic base	¼	None	None	None	Moderate	Severe
	½	"	"	"	None	None
	1	"	"	"	"	"
	1½	"	"	"	"	"
Pyrenone Grain Dust. Inorganic base	¼	None	None	None	None	None
	½	"	"	"	"	"
	1	"	"	"	"	"
	1½	"	"	"	"	"
Untreated Check 1 (infested April 26, 1950)		Severe	Severe			
Untreated Check 2 (infested Dec. 13, 1950)			Moderate	Severe		
Untreated Check 3 (infested Oct. 18, 1951)					Severe	Severe

Notes: Original weight of beans: 397 grams in each container.
Infestation introduced: April 26, 1950: 11 infested Red Kidney beans in each container. December 13, 1950: 10 infested Red Kidney beans and 5 adult weevils in each container. October 18, 1951: 15 adult weevils in each container.

TABLE 11

Comparison of Black Pepper, Pyrenone Grain Dust, and Diatomaceous Dust for Bean Weevil Control

Treatment	Quantity	October 25, 1951		February 12, 1952		October 4, 1952	
		Infestation	Loss[1] weight	Infestation	Loss[1] weight	Infestation	Loss[1] weight
	(teaspoon)		(grams)		(grams)		(grams)
Black Pepper, Dainty Dot	1/16	Severe	152.8	—	—	—	—
	⅛	None	2.0	Medium	5.0	Severe	165.5
	¼	None	1.0	Light	1.5	Light	0
	½	None	2.3	None	0	None	0
Black Pepper, McCormick Ordinary grind	1/16	Severe	104.5	—	—	—	—
	⅛	None	.5	Medium	0	Severe	157.5
Black Pepper, McCormick Finely ground	1/16	None	1.5	Medium	2.0	Severe	271.5
	⅛	None	.3	Light	0	Medium	0
Pyrenone Grain Dust[2] Organic base	1/16	Severe	115.8	—	—	—	—
	⅛	None	2.5	Medium	4.0	Severe	184.0
Pyrenone Grain Dust[3] Inorganic base	1/16	None	1.5	None	.2	Medium	1.5
	⅛	None	2.5	None	.7	None	2.7
Diatomaceous Dust Celite 209	1/16	None	.5	Light	0	Light	0
	⅛	None	1.8	None	.5	None	.2
	¼	None	1.3	None	0	None	0
	½	None	.5	None	0	None	0
Pyrophyllite Dust Pyrax ABB	1/16	Severe	177.5	—	—	—	—
	⅛	Severe	163.5	—	—	—	—
	¼	Medium	29.8	Severe	105.0	—	—
	½	Light	.8	Medium	28.0	Severe	169.5
Infested—No treatment (1)		Severe	210.3	—	—	—	—
Infested—No treatment (2)		—	—	Medium	15.0	Severe	200.0
Noninfested—No treatment		None	—	None	—	None	—

[1] Average loss per container compared to weight of noninfested checks.
[2] Contains .80% Piperanyl Butoxide and .04 Pyrethrins in wheat-dust base.
[3] Contains .80% Piperonyl Butoxide and .04 Pyrethrins in inorganic base.

Notes: Infestation introduced: March 19, 1951, 10 infested Red Kidney beans and 10 adult weevils in each infested container. October 25, 1951, 30 adult weevils added to each infested container.

TABLE 12

Comparison of 7 Kinds of Inert Dust for Bean Weevil Control

Treatment	October 9, 1951	
	Infestation	Loss[1] weight
(1/16 teaspoon of each dust)		(grams)
Talc, Emtco 23	Severe	173.7
Talc, Emtco 42	Severe	144.7
Argosite Clay 200 mesh	Severe	148.5
Argosite Clay 33 mesh	Severe	149.2
Homer Clay A.F.	Severe	138.7
Pyrax ABB	Severe	145.2
Continental Clay	Severe	131.7
No treatment	Severe	203.2

[1] Average loss per container, compared to original weight of beans.

Notes: Infestation introduced: May 29, 1951, 25 infested Red Kidney beans in each container.

TABLE 13

Comparison of Several Kinds of Inert Dusts for Bean Weevil Control

Material	April 27, 1953		Aug. 5, 1953		Oct. 6, 1953		Dec. 22, 1953		Jan. 25, 1954		Percentage[2] of beans with holes
	Infestation	Loss[1] weight	Infestation	Loss[1] weight	Infestation	Loss[1] weight	Infestation	Loss[1] weight	Infestation	Loss[1] weight	
(1/8 teaspoon of each dust)		(grams)		(grams)		(grams)		(grams)		(grams)	
Talc, EMTCO 23	Trace	18.0	Severe	134.8	Severe	209.5	Severe	218.3	Severe	224.0	99.4
Talc, EMTCO 42	Trace	19.8	Severe	109.3	Severe	190.3	Severe	206.5	Severe	212.8	98.7
Argosite Clay, 200 mesh	Trace	25.0	Severe	167.0	Severe	221.0	Severe	229.0	Severe	234.8	99.4
Homer Clay AF	Trace	16.0	Medium	49.0	Severe	161.5	Severe	194.5	Severe	203.3	98.0
Continental Clay	None	16.0	Light	38.8	Severe	118.8	Severe	159.8	Severe	173.0	93.0
Barden Clay	None	23.5	Medium	74.0	Severe	149.0	Severe	178.0	Severe	186.5	96.3
Slate Dust	Trace	31.3	Medium	56.8	Severe	137.8	Severe	195.3	Severe	212.5	97.8
Gypsum, No. 1 Terra Alba	Light	35.0	Severe	171.0	Severe	233.0	Severe	236.0	Severe	241.3	100.0
Gypsum, No. 1 S.W. Filler	Light	32.3	Severe	132.8	Severe	215.3	Severe	226.3	Severe	233.8	99.3
Lime, Hydrated Spray	Trace	24.5	Medium	79.3	Severe	153.0	Severe	227.3	Severe	232.0	99.9
Diatomaceous, Celite 209	None	24.5	Trace	21.0	Light	38.0	Medium	72.8	Severe	91.3	49.6
No treatment, infested	Light	31.8	Severe	162.0	Severe	222.5	Severe	225.3	Severe	236.5	98.5

[1] Average loss per container, compared to original weight of 400 grams of beans in each container.
[2] Average of 3 random samples of 100 beans from each container.

Notes: Infestation introduced: February 4, 1953. Pill box, containing 24 infested beans, placed in each container.

TABLE 14

Comparison of Different Kinds of Diatomaceous Dusts for Control of the Bean Weevil

Material	Quantity	Feb. 5, 1953 Infes-tation	Feb. 5, 1953 Loss[1] weight	Mar. 16, 1953 Infes-tation	Mar. 16, 1953 Loss[1] weight	Apr. 28, 1953 Infes-tation	Apr. 28, 1953 Loss[1] weight	Aug. 4, 1953 Infes-tation	Aug. 4, 1953 Loss[1] weight	Oct. 5, 1953 Infes-tation	Oct. 5, 1953 Loss[1] weight	Dec. 21, 1953 Infes-tation	Dec. 21, 1953 Loss[1] weight	%[2] beans with holes
	(teaspoon)		(grams)		(grams)		(grams)		(grams)		(grams)		(grams)	
Celite 209	⅛	None	0	Trace	.3	Trace	.8	Light	1.3	Light	10.0	Medium	20.1	22.3
	⅛	Trace	0	Light	0	Light	.8	Light	2.0	Light	14.8	Medium	37.0	26.1
	1/16	Trace	0	Light	0	Light	0	Medium	25.0	Severe	95.8	Severe	127.0	84.3
	1/16	Trace	1.8	Trace	1.3	Light	2.5	Medium	18.8	Severe	62.0	Severe	92.0	66.5
	1/16	None	0	Trace	0	Trace	0.5	Medium	0	Severe	41.8	Severe	83.5	49.8
	1/16	Trace	2.3	Trace	1.3	Light	1.8	Medium	9.5	Severe	13.5	Severe	131.5	77.3
Celite 270	⅛	Trace	2.8	Trace	3.3	Light	3.8	Severe	71.0	Severe	113.0	Severe	121.5	70.6
	1/16	Medium	1.3	Severe	4.0	Severe	25.0	Severe	129.8	Severe	188.0	Severe	193.5	99.3
Celite 400	⅛	None	1.8	Trace	2.3	Light	3.3	Medium	9.3	Severe	63.0	Severe	80.8	49.6
	1/16	Light	2.0	Medium	4.5	Medium	17.3	Severe	94.3	Severe	160.0	Severe	181.8	98.9
Super Floss	⅛	Light	1.8	Medium	13.0	Severe	43.3	Severe	111.5	Severe	157.8	Severe	159.5	96.0
	1/16	Light	2.8	Severe	38.2	Severe	65.5	Severe	115.8	Severe	153.0	Severe	148.8	75.0
Dicalite IG1	⅛	Trace	1.3	Light	1.3	Light	2.0	Light	3.0	Medium	15.3	Severe	42.3	32.8
	1/16	Light	.8	Light	1.3	Medium	2.3	Medium	4.3	Severe	44.3	Severe	123.5	74.1
Dicalite IG2	⅛	None	3.0	Trace	2.8	Light	4.0	Medium	6.8	Severe	37.5	Severe	59.5	44.4
	1/16	Trace	0	Medium	0	Medium	4.0	Severe	67.0	Severe	139.8	Severe	161.5	93.5
Dicalite IG3	⅛	None	2.0	None	1.8	Light	2.8	Medium	4.8	Medium	14.0	Severe	30.8	31.9
	1/16	Trace	3.8	Light	3.5	Light	4.0	Medium	5.5	Severe	31.8	Severe	96.5	73.1
Dicalite Speed-plus	⅛	Medium	6.0	Medium	26.8	Severe	77.8	Severe	180.5	Severe	204.8	Severe	197.5	99.6
	1/16	Medium	4.8	Severe	36.0	Severe	90.5	Severe	183.0	Severe	206.3	Severe	199.0	100.0
Dicalite Speedflow	⅛	Trace	1.8	Trace	0	Trace	1.8	Severe	24.3	Severe	68.5	Severe	87.0	49.5
	1/16	Trace	1.8	Trace	3.3	Light	8.5	Severe	69.0	Severe	162.5	Severe	177.5	97.5
No treatment infested	—	Medium	7.3	Severe	33.0	Severe	89.3	Severe	191.0	Severe	208.8	Severe	201.0	99.9

[1] Average loss per container, compared to weight of noninfested checks.
[2] Average of 2 random samples of 100 beans from each container.

Note: Infestation introduced: December 3, 1952, a pill box containing 10 clean beans, and 10 infested beans, and 5 adult weevils, placed in each infested container.

TABLE 15

Comparison of Three Brands of Diatomaceous Dust
Dosage: ¼ teaspoon of dust to 400 grams of beans

Number of holes per bean	Percentage[1] of beans having specified number of exit holes			
	No treatment	Celite 209	Dicalite IG 2	Dicalite IG 3
0	.167	99.375	98.500	100.000
1	.167	.375	.625	
2	.333	.000	.000	
3	.500	.125	.250	
4	1.833	.125	.000	
5	2.833		.125	
6	4.667		.375	
7	4.000		.000	
8	6.500		.000	
9	7.167		.000	
10	11.167		.000	
11	13.333		.125	
12	11.000			
13	9.667			
14	7.500			
15	7.167			
16	4.000			
17	3.500			
18	1.333			
19	1.667			
20	.667			
21	.333			
22	.333			
23	.167			
Average[1] holes per 100 beans	1135.50	1.25	5.63	.00

[1] Nontreated beans: Average of 6, 100-bean random samples.
Treated beans: Average of 8, 100-bean random samples for each brand of dust.

Notes: Original weight of beans: 400 grams in each container.
Replication: Untreated beans: 3 containers.
Treated beans: 4 containers for each brand of dust.
Infestation introduced: August 28, 1953—A pill box containing 24 infested beans placed on top of beans in each container.
Results: Determined by examination and counts at the termination of the experiment, April 21, 1954.

TABLE 16

Comparisons of Numbers of Weevils and Dosage of Celite 209

Quantity of Celite 209	Weevils in each container	February 15, 1952		October 6, 1952	
		Infestation	Loss[1] of weight	Infestation [2]	Loss[1] of weight
(teaspoon)			(grams)		(grams)
None	None	None	—	None	—
None	5	Light[3]	3.3[3]	Severe[3]	105.8[3]
1/16	5	None	0	None	0
⅛	5	None	0	None	0
1/16	20	None	0	1	0
⅛	20	None	0	1	0
1/16	80	None	0	17	0
⅛	80	None	0	4	0

[1] Average loss per container, compared to weight of noninfested checks.
[2] The numbers in this column refer to the total numbers of beans with exit holes found in the 4 containers.
[3] Infestation developed in only 2 containers. The results shown here refer only to the 2 containers in which infestation developed in the beans.

Note: Infestation introduced: November 2, 1951, the number of weevils shown in the table, placed in each container.

TABLE 17

Comparison of Methods of Introducing Infestation among Beans Treated with Celite 209

Number of exit holes per bean	Number[1] of beans having specified number of exit holes					
	A	B	C	D	E	F
0	4.000	100.00	98.750	99.500	99.250	99.500
1	.250		.375	.125	.375	.250
2	1.125		.500	.0	.0	.250
3	1.250		.250	.0	.125	
4	2.375		.0	.0	.0	
5	3.625		.125	.250	.0	
6	4.375			.125	.0	
7	6.500				.125	
8	7.250				.0	
9	9.875				.0	
10	10.875				.0	
11	10.625				.0	
12	9.125				.0	
13	10.250				.125	
14	7.375					
15	4.625					
16	3.250					
17	1.250					
18	1.000					
19	.750					
20	.125					
21	.125					
Total No.[1] holes per 100 beans	1004.125	.0	2.750	2.125	3.250	.750

[1] Average of eight 100-bean random samples from each treatment.

Notes: A—No dust treatment; 12 severely infested Red Kidney beans mixed with the beans in each container.
B—Celite 209, ¼ teaspoon; 12 severely infested Red Kidney beans mixed with the beans in each container.
C—Celite 209, ¼ teaspoon; 24 severely infested Red Kidney beans mixed with the beans in each container.
D—Celite 209, ¼ teaspoon; 12 severely infested Red Kidney beans in pill box placed on top of the beans in each container
E—Celite 209, ¼ teaspoon; 24 severely infested Red Kidney beans in pill box placed on top of the beans in each container.
F—Celite 209, ½ teaspoon; 24 severely infested Red Kidney beans in pill box placed on top of the beans in each container.
Infestation introduced: December 28, 1953.
Results: Determined by examination and counts July 5, 1954.

TABLE 18

Treatment of Bags for Protecting Beans from Weevil Infestation

Container	Bag	Treatment of bag	November 14, 1952 Percentage[1] of beans with holes
1	a	No treatment	21.5
	b	Celite 209	0
2	a	No treatment	82.3
	b	Celite 209	0
3	a	No treatment	20.8
	b	Celite 209	0
4	a	No treatment	11.0
	b	Celite 209	0
Average	a	No treatment	33.9
	b	Celite 209	0

[1] Average of 4 random samples of 100 beans from each bag.

Notes: Original weight of beans: 400 grams in each bag.

Containers: Fiber, cylindrical, 1 gallon capacity, 2 bags of beans in each container.

Bags: Each bag 6 inches deep and 5 inches wide; made of grain-bag cloth 40 x 40 threads per inch.

Treatment: The beans were not treated. The cloth of the bag "a" in each container was impregnated with Celite 209. Bag "b" in each container was not treated.

Infestation introduced: November 10, 1951, 100 adult weevils placed in each 1-gallon container, exposing both the treated and the nontreated bags equally to the weevils.

TABLE 19

Comparison of Four Different Dosages of Diatomaceous Dust (Dicalite IG 3) for Bean Weevil Control

Cooperative Test with Commercial Cannery

Number of exit holes per bean	Number[1] of beans having specified number of exit holes				
	No treatment	½ ounce dust[2]	¾ ounce dust[2]	1 ounce dust[2]	2 ounces dust[2]
0	23.0	79.5	76.0	71.5	77.5
1	5.5	13.5	11.0	18.5	12.0
2	8.5	5.5	6.0	5.0	6.5
3	8.5	1.0	4.5	3.5	1.5
4	6.0	.5	1.0	1.5	2.5
5	7.5		1.5		
6	7.0				
7	9.5				
8	5.5				
9	6.5				
10	5.0				
11	3.5				
12	1.0				
13	2.0				
14	0				
15	1.0				
Total number holes per 100 beans	462	29.5	48.0	45.0	39.5

[1] Average of two 100-bean random samples from each treatment.
[2] Quantity of dust per 100 pounds of beans.

Notes: Original weight of beans: 25 pounds in each bag.

Containers: Large paper bags, each containing 25 pounds of beans. Each paper bag was placed in a cloth grain bag for strength.

Replication: 4 bags for each treatment and the untreated check.

Infestation introduced: The beans were already infested with weevil larvae before the test began. Care was used to divide the beans into uniform lots of 25 pounds for the test. In addition to the prior infestation, a pill box containing 20 infested beans was placed in each bag, November 18, 1952.

Results: Determined by examination and counts of infestation at the termination of the experiment, April 23, 1953.

TABLE 20

Comparison of Four Different Dosages of Diatomaceous Dust (Celite 209) for Bean Weevil Control

Cooperative Test with Commercial Cannery

Number of holes per bean	Percentage[1] of beans having specified number of exit holes				
	No treatment	½ ounce dust[2]	¾ ounce dust[2]	1 ounce dust[2]	2 ounces dust[2]
0	6.75	95.25	98.40	99.50	99.80
1	3.95	1.55	.35	.25	.10
2	4.85	.70	.45	.05	.05
3	6.10	.35	.05	.10	.05
4	6.15	.30	.25	.05	
5	7.05	.40	.10	.00	
6	8.05	.35	.05	.00	
7	8.30	.20	.05	.00	
8	10.70	.20	.05	.00	
9	9.50	.20	.10	.00	
10	7.35	.00	.10	.05	
11	7.25	.15	.00		
12	4.70	.15	.05		
13	3.00	.10			
14	2.80	.00			
15	1.75	.05			
16	.70	.00			
17	.60	.00			
18	.30	.00			
19	.10	.05			
20	.00				
21	.05				
Average[1] holes per 100 beans	713.30	20.55	6.45	1.35	.35

[1] Average of 20, 100-bean random samples from each treatment.
[2] Quantity of dust per 100 pounds of beans.

Notes: Original weight of beans: 25 pounds in each bag.

Containers: Large paper bags, each containing 25 pounds of beans. Each paper bag was placed in a cloth bag for strength.

Replication: 2 bags for each treatment and the untreated check.

Infestation introduced: December 13, 1952.—A pill box containing 24 infested beans placed on top of the beans in each bag. January 10, 1953.—A second pill box containing 24 infested beans placed on top of the beans in each bag. January 19, 1953.—100 adult weevils placed in each bag. June 9, 1953.—A ½-pint container with 95 grams of infested beans placed on top of the beans in each bag.

Results: Determined by examination and counts of infestation at the termination of the experiment, February 23, 1954.

TABLE 21

Materials Tested for Bean Weevil Control

Material	1 teaspoon[1] weight	From
	(grams)	
Argosite Clay 200 mesh	3.5330	United Clay Mines
Barden Clay	2.1327	J. M. Huber Corporation
Continental Clay	2.3298	R. T. Vanderbilt Co.
Diatomaceous Dust		
Celite 209	0.8192	Johns-Manville Products Corp.
Celite 270	0.8736	" " " "
Celite 400	0.7242	" " " "
Micro-Cel 800	0.6186	" " " "
Super Floss	0.9495	" " " "
Dicalite IG 1	1.0301	The Dicalite Co.
Dicalite IG 2	1.0635	" " "
Dicalite IG 3	1.0591	" " "
Dicalite Speedflow	1.0117	" " "
Dicalite Speedplus	1.0427	" " "
Gypsum, No. 1 S.W. Filler	3.9491	U. S. Gypsum Co.
Gypsum, No. 1 Terra Alba	3.1998	" " "
Homer Clay AF	2.1347	United Clay Mines
Hydrated Lime	2.1295	Lee Lime Corporation
Pepper, Black		
Dainty Dot	1.8974	First National Stores
McCormick, ordinary	2.1616	McCormick and Co.
McCormick, fine	2.3118	" " "
Pyrenone Grain Dust, inorganic base	2.2630	U.S. Industrial Chemicals, Inc.
Pyrenone Grain Dust, organic base	1.7779	" " " "
Pyrophyllite Dust, Pyrax ABB	2.8765	R. T. Vanderbilt Co.
Slate Dust	2.7779	Portland-Monson Slate Co.
Talc, EMTCO 23	2.8480	Eastern Magnesia Talc Co.
Talc, EMTCO 42	3.0791	" " " "

[1] 1 level teaspoonful. The material was firmed into the spoon, but not packed. Average weight of 2 measurements.

LITERATURE CITED

Adams, R. E., Wolfe, J. E., Milner, Max, and Shellenberger, J. A. 1953. Aural Detection of Grain Infested Internally with Insects. Science 118:163-164.

Back, E. A. 1939. Weevils in Beans and Peas. U. S. Dept. Agr., Farmers' Bul. 1275 (1922 revised 1939).

Briscoe, H. V. A. 1943. Some New Properties of Inorganic Dusts. Jour. Royal Soc. of Arts. 91:593-607.

Flanders, Stanley E. 1930. Recent Developments in *Trichogramma* Production. Jour. Econ. Ent. 23:837-841.

Flanders, Stanley E. 1932. Temperature as a Measure of an Insect Population. Jour. Econ. Ent. 25:934.

Freeborn, Stanley B., and Wymore, Floyd H. 1929. Attempts to Protect Sweet Corn from Infestations of the Corn Ear Worm, *Heliothis obsoleta* (Fabr.). Jour. Econ. Ent. 22:666-671.

Harvill, Edward K., Hartzell, Albert, and Arthur, John M. 1943. Toxicity of Piperine Solutions to Houseflies. Contrib. Boyce Thompson Inst. 13:87-92.

Larson, A. O., and Fisher, C. K. 1938. The Bean Weevil and the Southern Cowpea Weevil in California. U. S. Dept. Agr., Tech. Bul. 593.

Lathrop, F. H. 1953. Bean Weevils; Diatom Dust Provides Protection for Beans. Maine Agr. Exp. Sta. Maine Farm Research, July 1953, pages 4 and 5.

Lathrop, F. H., and Keirstead, L. G. 1946. Black Pepper to Control the Bean Weevil. Jour. Econ. Ent. 39:534.

Manter, J. A. 1917. Notes on the Bean Weevil (*Acanthoscelides* [*Bruchus*] *obtectus* Say). Jour. Econ. Ent. 10:190-193.

McIndco, N. E., and Sievers, A. F. 1924. Plants Tested for or Reported to Possess Insecticidal Properties. U.S.D.A. Bul. 1201.

Menusan, H., Jr. 1934. Effects of Temperature and Humidity on the Life Processes of the Bean Weevil, *Bruchus obtectus* Say. Ann. Ent. Soc. America, 27:515-526.

Menusan, H., Jr. 1935. Effects of Constant Light, Temperature, and Humidity on the Rate and Total Amount of Oviposition of the Bean Weevil, *Bruchus obtectus* Say. Jour. Econ. Ent. 28:448-453.

Metcalf, Z. P. 1917. Lime as an Insecticide. Jour. Econ. Ent. 10:74-78.

Nelson, H. D., and Fisher, C. K. 1952. Control of Insects That Attack Dried Beans and Peas in Storage. U.S.D.A., Agr. Res. Admin., Bu. of Ent. and Pl. Quar., EC-27.

Synerholm, Martin E., Hartzell, Albert, and Arthur, John M. 1945. Derivatives of Piperic Acid and Their Toxicities Toward Houseflies. Contrib. Boyce Thompson Inst. 13:433-442.